CLIVAR

The Principal Research Areas

D4: Pacific and Indian Ocean Decadal Variability

Goal:
Improving the description and understanding of the decadal variability and its predictability in the Pacific and Indian Ocean basins, and its relationship with ENSO and teleconnections.

Introduction

The sea surface temperatures (SST) in the tropical Pacific and at mid-latitudes influence the climate around the Pacific basin. At decadal time scales (peaking in the 20-30 year range) the SST pattern is symmetric about the equator with the tropics out of phase with mid-latitudes; the amplitude at mid-latitudes is approximately equal to the tropical amplitude (Figs. 1 and 2). This pattern is roughly similar to that of the strong ENSO variability at seasonal to interannual time scales, with the exception that the amplitude of ENSO is much higher in the tropics than at mid-latitudes. The 20-30 year mode modulates the more rapid ENSO signal with sometimes significant and marked effects. The decadal pattern of SST correlates strongly with the Pacific-North American (PNA) pattern on decadal time scales; it is likely to be part of a much larger pattern which also includes the Indian Ocean and possibly the western North Atlantic. The consequences of the extremes of this 20-30 year mode are well known in the North Pacific, where it is associated with the variations of the strength of the Aleutian Low; impacts include those on temperature and water resources, and on a wide range of environmentally-related variables such as fish stocks.

Observations

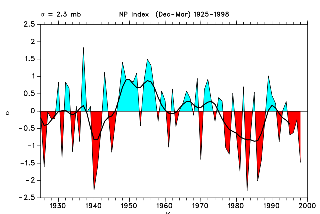


Fig. 1: The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W and shows a high level of decadal time scale variability (after Trenberth and Hurrell, 1994, Climate Dynamics, 9, 303-319).

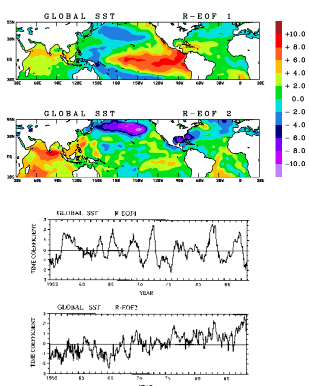


Fig. 2 a) (upper panel): Spatial patterns of the leading two R-EOF modes of monthly mean global-scale SST anomalies based on data for 34 years from January 1955 to December 1988, derived from the R-EOF analysis. Contour interval is 2.0 in relative units.
b) (lower panel): Time coefficient (i.e. factor scores) of the first two R-EOF modes over 34 years from January 1955 to December 1988 (Kawamura, 1994, J. Phys. Oceanogr., 24, 707-715).

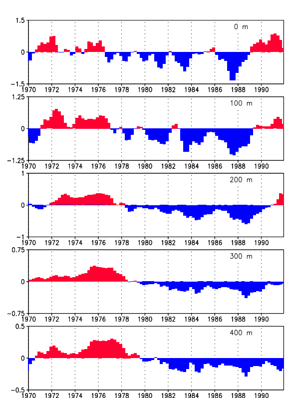


Fig. 3: seasonal temperature anomalies (°C) in the central Pacific region at selected depths. Note that the scale for the temperature anomalies is different for each depth (Deser et al., 1996, J. Climate, 9, 1840-1855).

Science Questions

The key thrusts for CLIVAR research in this principal research area are directed at variability in two regions:

Pacific Ocean

The basic questions we wish to answer for the Pacific are:

- **How can we better describe and understand decadal variability in the Pacific?**
- **To what extent is this variability predictable and what are the means to realise this predictability?**

Indian Ocean

For the Indian Ocean, of which we have much less information, the key questions are:

- **To what extent can we better describe and understand decadal variability in the Indian Ocean and South Pacific, including monsoonal and mid-latitude variability?**
- **How is it related to the tropical/North Pacific mode?**
- **Is there a relation to the Southern Ocean propagating mode or to variability in the Atlantic?**
- **Is the decadal variability predictable?**

The Indo-Pacific Decadal component of CLIVAR will proceed through a combination of modelling and observations, tied together through diagnosis of model results and observational analyses separately and together. The long time scales of the phenomena of interest present special observational problems and the active participation of the ocean requires special efforts to make ocean measurements.

Observing Needs

Observing needs for description and modelling of the decadal to centennial climate in the Pacific and Indian range from thin global networks of sustained observations, to routine monitoring of important sites such as boundary currents and throughflows, to reconstruction of climate records from paleoclimatic data, to focused experiments comprised of observations and modelling to understand specific processes which govern climate variability.

Broad-scale and ongoing routine observations

The maintenance of a whole suite of observations is required to fulfill the multiple needs of climate research in the Pacific and Indian Ocean region. In addition, sustained observations for different variables have to be established in the large data sparse areas of the Indian and South Pacific Ocean. Long-term satellite observations will help to improve different meteorological and oceanographic data sets along with the *in situ* data needed for validation.

The CLIVAR Initial Implementation Plan recommended maintenance or enhancement of the following observing system within the Indo-Pacific region:

- **Broadscale XBT network**
- **High resolution XBT network**
- **Salinity measurements**
- **Surface drifters (SST, surface pressure, near-surface velocity, SSS)**
- **Profiling subsurface floats (T(z), S(z))**
- **Altimetry (Sea Surface Height (SSH))**
- **Sea level**
- **Shore stations:**
- **Repeat hydrography**
- **TAO/TRITON array**
- **Surface meteorological observations**
- **Boundary current monitoring**

Long-term climate observations of meteorological and oceanographic variables provide important data for the investigation of decadal variability as well as they are essential for model verification and intercomparison.

Above: Sea level measurements with tide gauges (picture above, © G. Meehl) provide one of the few long-term measurements which are already available for study of natural and anthropogenic climate variations. Left: Quasi operational oceanographic measurements e.g. by the TAO and TRITON moorings (left pictures, © JAMSTEC; NOAA/PMEL) are the backbone of a long-term upper ocean observing system.

Upper left: Sustained measurements taken during field campains are helpful tools to reduce the data gaps within large parts of the worlds ocean (upper: automatic weather balloon launch, © NCAR; lower: ADCP launch, © NOAA/PMEL)

Modelling & Prediction

- Coupled models have reproduced decadal modes in the Pacific, like the 'Latif-Barnett mode' (Latif et al., 1994 (Fig. 4)) and the (North Pacific) mode (Yukimoto et al., 1996, Climate Dynamics, 12, 667-683) (see also Fig. 2).
  What are the conditions for reproducing these modes in the models?
- There are different theories to elucidate the decadal variability of ENSO.
  What are the mechanisms that influence ENSO on decadal timescales?
- On the assumption that Pacific decadal variability is represented by a coupled atmosphere-ocean mode, it is necessary to conduct simulated model experiments to determine the predictability of this mode.
  If predictability exists for SST and in what regions over what time scales?
  What is the ultimate limit of predictability?
  Which data are the relevant data for initialisation; and what is an optimal measuring system for initialising the models?

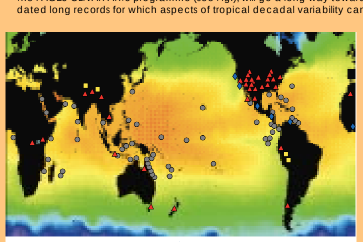
Focused Research Projects

The following focused research projects have been proposed accordingly to the Initial CLIVAR Implementation Plan:

- **A Pacific basin-wide extended climate study (BECS)**
- **Mixing in the mixed layer and upper thermocline**
- **Interaction of the upper thermocline with the surface layer: subduction**
- **Direct observations of circulation**
- **Enhanced surface meteorology**
- **Enhanced salinity measurements**
- **Subpolar North Pacific study**
- **Southern Hemisphere subduction**
- **Monsoon variability**
- **Effects of western boundary currents on regional climate**
- **Indonesian throughflow**

Proxy records of decadal & centennial variability

- Upper ocean and atmospheric records are inadequate for defining decadal to centennial time scales in the Indian and Pacific Oceans except in a very few places where records are of sufficient length.
- Climate proxies can provide records of several hundred up to 1000 years at a number of sites and longer records in ice cores.
- Paleoclimate data from corals, varved sediments, tree rings, and ice cores have the potential to provide detailed reconstructions of tropical sea surface temperature, salinity, and rainfall, as well as teleconnected responses on land and in mid-latitudes.
- Spatial fields of paleoclimate data are far more valuable than individual sites.
- The PAGES-CLIVAR ARTS programme (see Fig.), will go a long way towards providing cross-validated long records for which aspects of tropical decadal variability can be reconstructed.



Sites where paleoclimatic research on tropical climate systems and their teleconnections is underway, using archives with proven or potential annual resolution. This map includes sites where work is just beginning. In certain regions, individual sites are too numerous to identify and symbols represent regional efforts (e.g. tree-rings in North America; corals on the Great Barrier Reef) (PAGES,/CLIVAR Intersection, 1996, available from the PAGES IPO, Bern, Switzerland).

Decadal Variability in the Pacific:

- Four Hypotheses -

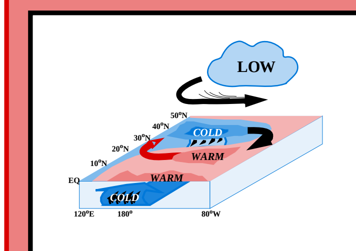


Fig. 4: Schematic diagram of possible mechanisms of decadal climate variability. Extratropical decadal climate variability may be caused by a cycle involving unstable air-sea interactions between the subtropical gyre circulation in the North Pacific and the Aleutian low-pressure system. Long-term fluctuations of the tropical SSTs may, presumably, be induced by an influx of water from higher latitudes which subducts in the North Pacific and flows southeastward along the surfaces of constant density before equatorial upwelling brings it back to the surface. The tropical SST anomalies may in turn also affect the Aleutian low-pressure system (S. Venzke, 1998, Ocean-atmosphere interactions of decadal timescales, Thesis, Max-Planck-Institut für Meteorologie, Hamburg, 100pp).

1. Subtropical air-sea interaction produces ocean temperature anomalies that are advected along isopycnal surfaces to the equator, where they upwell and result in equatorial SST anomalies (years to decades). This produces a rapid negative feedback via atmospheric teleconnections (Gu and Philander, 1997).

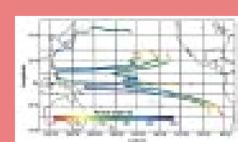


Fig. 5: The paths of water parcels over a period of 16 years after subduction off the coasts of California and Peru as simulated by means of a realistic oceanic general circulation model forced with the observed climatological winds. From the colours, which indicate the depth of the parcels, it is evident that parcels move downward, westward, and equatorward unless they start too far to the west off California, in which case they join the Kuroshio Current. Along the equator they rise to the surface while being carried eastward by the swift Equatorial Undercurrent (Gu, Philander, 1997, Science, 275, 805-807).

2. Advection of SST anomalies from the Sub-Arctic Frontal Zone, to the equator via the eastern limbs of the subtropical gyres (one decade) causing a rapid negative feedback trough atmospheric teleconnections (White and Cayan, 1998, 103, 21335-21354).

3. Excitation of Rossby waves similar in pattern to, but less equatorially-confined than, ENSO. The subsequent slow propagation of these waves to the western boundary and their reflection along the equator changes the sign of the equatorial thermocline depth and thus the SST (on decades). Then a rapid negative feedback as atmospheric teleconnections change the sign of extra-tropical wind stress curl, forcing waves of opposite sign (Zhang, Wallace, and Battisti, 1997, J. Climate, 10, 1004-1020).

4. SST meridional gradient anomalies in the North Pacific subtropical gyre alter the jet stream intensity, then the gyre circulation adjusts through the propagation of wind-forced Rossby waves (on decades). These change the poleward advection of heat by the Kuroshio which provides a negative feedback to the SST gradient (Latif et al., 1994, Science, 266, 634-637).

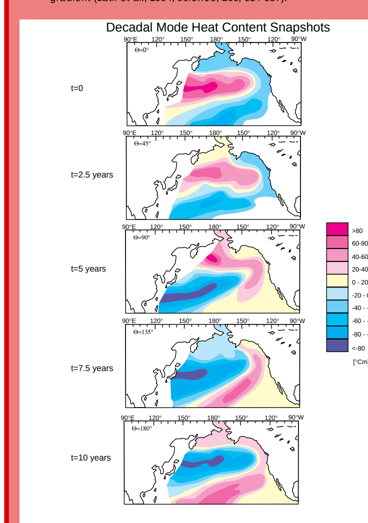


Fig. 6: Reconstruction of anomalous heat content from the output of a coupled model run in the Pacific Ocean. The individual panels show the progression of heat content anomalies at approximately 2.5 years apart (Latif et al., 1994, Science, 266, 634-637).